J. Anat. (1998) **192**, pp. 279–285, with 3 figures Printed in the United Kingdom

Short Report

Patterns of sexual, bilateral and interpopulational variation in human femoral neck-shaft angles

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(*Accepted 18 November 1997*)

ABSTRACT

Data on femoral neck-shaft angles were collected for 30 modern, historic and prehistoric human population samples, and analysed with respect to sexual dimorphism, bilateral asymmetry, geographical patterning and general economic level. Although some samples had modest sexual dimorphism in this angle, and some individuals exhibited clear asymmetry, there were no consistent patterns of sexual or side differences across human populations. Similarly, there was no evidence for geographic differences, since broad regional groups lacked significant differences and mean angles were not correlated with latitude. However, there is a significant increase in mean neck-shaft angles across populations with an increasingly sedentary existence and with mechanisation. The last reflects the developmental plasticity of this feature with respect to habitual load levels during ontogeny of the hip region.

Key words: Skeletal morphogenesis; industrialisation.

INTRODUCTION

There has been ongoing interest in degrees and patterns of variation of the medial inclination of the femoral head and neck relative to its diaphysis at least since Charpy (1885) and Humphry (1889), with the extreme vertical and horizontal positions normally characterised as coxa valga and coxa vara. This orientation is most effectively evaluated through its quantification by the femoral neck-shaft angle (collo-diaphyseal, cervicodiaphyseal angle, or angle of inclination) [Martin number 29 (Bräuer, 1988)]. Despite ongoing anthropological (e.g. Twiesselmann, 1961; Trinkaus, 1993; Grine et al. 1995) and especially orthopaedic (e.g. Houston & Zaleski, 1967; Walensky & O'Brien, 1968; Henriksson, 1980; Hoaglund & Weng, 1980; Clark et al. 1987; Yoshioka et al. 1987; Faulkner et al. 1993; Laplaza et al. 1993; Yamaguchi, 1993; Saji et al. 1995) interest in the ranges and patterns of variation of the femoral neck-shaft angle under varying normal and abnormal conditions, there has been little consideration of normal ranges of variation of the trait across human populations. We therefore present data on the femoral neck-shaft angle from diverse human populations, past and present, as a background to normal variation among living humans. In addition, it is necessary to address suggestions that femoral neck-shaft angles pattern according to sex, side and geographical origin.

MATERIALS AND METHODS

The data presented here were derived from personal measurement of prehistoric, early historic (medieval) and modern (cadaveric) skeletal remains, similar data collected and (in part) published by other authors, and data derived from radiographic studies of extant humans (Table 1). In every case, to the extent determinable from skeletal material and published notes, the individuals were developmentally and clinically normal with respect to conditions which might affect the development of the femoral neck-shaft angle.

In as many cases as possible, the individual data points were employed to reconstruct distributions (Fig. 1) and evaluate sex (Table 2) and side (Table 3)

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differences. However, additional samples for which only summary statistics were available were included to maximise the perceived patterns of inter and intrapopulational variation (Table 1).

The femoral neck-shaft angle provided here is measured on the anterior surface of the femur as the obtuse angle between the neck axis and the proximal femoral diaphysis. The neck axis is the midline between the proximal and distal borders of the neck, and the diaphyseal axis is defined by the mediolateral diaphyseal midpoints in the subtrochanteric and midshaft regions. Intra and interobserver error in this angle is due to variation in the determination of the neck axis, given the irregular profiles of its proximal and distal borders. Yet, remeasurement by one of the authors (E.T.) of a sample of 40 Euroamerican femora produced a median intraobserver error of 0° and a mean error of 0.4°. Comparisons of those measurements to determinations made on the same bones by Tompkins et al. (1988) produced a median and mean interobserver error of 2°. Similarly, independent determinations of neck-shaft angles using different techniques on 2 overlapping samples of femora of Pecos Pueblo Amerindians by Ruff (1981) and E.T. produced sample means of 126.3° ($n = 120$) and 126.7° ($n = 50$) respectively. Consequently, even though measurement error on individual specimens (skeletal or radiographic) may be several degrees, the error tends to be random and usually does not exceed 1°–2° on average across a sample. It is nonetheless likely that interobserver differences in technique introduce additional error, differences which are difficult to control even when individual data are available from the authors; it is expected that such variation in technique is random and hence should not bias results across reasonable numbers of samples.

Since 4 of the samples (Nigerians, Parisians, northeastern US Euroamericans and Hong Kong Chinese) were derived from uncorrected radiographic measurement, it was necessary to correct for geometric increases in neck-shaft angle from varying degrees of femoral anteversion (or torsion). This was done following Dunlap et al. (1953) using individual anteversion angles or sample means as available.

In addition to considerations of sex and side, it is also appropriate to evaluate patterns of variation in neck-shaft angle relative to inferred levels of mobility and physical activity given the developmental plasticity of neck-shaft angles (see below). In order to do this, the samples were divided into variably mobile hunting-and-gathering (or foraging) populations, small scale agricultural populations, including both farming and pastoralist societies lacking access to mechanised equipment, and modern industrialised society (largely urban) populations. Despite considerable variation within each of these categories, both intra and interpopulational, in terms of habitual biomechanical loads on the lower limbs, these general categories should permit evaluation of the degree of patterning across diverse human economic/adaptive patterns, from Paleolithic and recent mobile foragers to late 20th century mechanised urban populations.

Furthermore, in order to evaluate whether neck-shaft angles might pattern geographically or eco-geographically, variation in mean neck-shaft angles was evaluated with respect to broad geographical regions and with respect to latitude. For the former, the samples were divided into Sub-Saharan African, European/Mediterranean, east Asian, and Native American groups (the Australian and Polynesian samples were not included, given the limited data from those regions). For the latter, recent immigrant populations (all North Americans of European ancestry) were not considered.

RESULTS AND DISCUSSION

Morphogenetic considerations

Since Humphry (1889), it has been noted that there is a general inverse relationship between biomechanical loading levels at the hip and the neck-shaft angle. In particular, femoral neck-shaft angles are characteristically very high (±150°) in neonatal modern humans and then gradually decrease during development, reaching adult values during adolescence (Humphry, 1889; Billing, 1954; Houston & Zaleski, 1967; Henriksson, 1980; Laplaza et al. 1993; Yamaguchi, 1993). Although there appears to be a minimal decrease in the angle in infants and juveniles who do not assume normal weight-bearing of the lower limb (Houston & Zaleski, 1967; Laplaza et al. 1993; Yamaguchi, 1993), the normal process of reduction in the angle to a more varus orientation of the femoral neck during development is dependent on the assumption of normal weight-bearing through the hip region and increasing locomotor activity levels during development (Morscher, 1967; Houston & Zaleski, 1967; Serafimov, 1974; Houston, 1978; Laplaza et al. 1993; Yamaguchi, 1993).

This is particularly evident in cases of reduced or absent weight-bearing during development. This is seen in infantile congenital dislocated hip (Morscher, 1967; Serafimov, 1974; Houston, 1978), slipped femoral capital epiphysis (Loder et al. 1993), cerebral palsy (Laplaza et al. 1993; Yamaguchi, 1993) and immature idiopathic scoliosis (Saji et al. 1995). In

Table 1. *Summary statistics for femoral neck-shaft angles (in degrees) by economic category*

	Mean (deg)	S.D. (deg)	N
Foragers			
Khoisan (South Africa)[1]	123.2	—	47
Eurasian Paleolithic early modern humans[2]	124.5	7.4	31
East Asian—Yoshiko Jomon (Japan)[3]	124.5	4.5	117
European/North African Mesolithic humans[2]	125.8	7.2	26
Australians[4]	127.6	—	260
Agriculturalists			
Africans (South Africa)[5]	121.9	4.6	361
European (France)[6]	122.9	7.6	32
Amerindian—Rio Grande Pueblo (USA)[2]	124.8	5.6	84
East Asia—Tsukumo Neolithic (Japan)[7]	124.6	3.9	46
East Asians—Formosa (China)[8]	125.6	—	298
Europeans—Rothwell Medieval (Britain)[9]	126.3	5.1	134
Europeans—Neolithic (Italy)[10]	126.3	—	35
Amerindians—Pecos Pueblo (USA)[2]	126.7	4.4	50
Sub-Saharan Africans—Zulu (Africa)[1]	126.7	—	50
Europeans—Mistihalj Medieval (Serbia)[2]	128.5	4.7	50
Europeans—Lapps (Norway)[11]	129.1	—	280
Africans (Nigeria)[12]	130.1	6.7	256
Amerindians—Illinois Woodland (USA)[13]	130.8	3.5	153
South Asians (India)[14]	131.1	3.8	151
Amerindians—Illinois Mississippian (USA)[13]	131.6	3.7	48
Polynesians—Easter Island[15]	133.7	5.6	21
Urban			
East Asians (Japan)[16]	128.4	0.9	60
Europeans—Paris (France)[17]	129.1	7.0	73
Euroamericans—Albuquerque (USA)[2]	129.4	5.5	55
East Asians—Kinai (Japan)[18]	130.5	4.9	50
Euroamericans (Canada)[19]	131.0	—	32
East Asians—North Chinese (China)[20]	131.2	—	137
Europeans—Brussels (Belgium)[21]	133.1	5.6	186
Euroamericans—Northeast US (USA)[22]	135.0	6.8	55
East Asians—Hong Kong (China)[22]	136.2	3.6	53

[1] Summary statistics from Grine et al. (1995); [2] data from Trinkaus (1993, pers. observ.) and Heller (pers. comm.); [3] data from Ishisawa (1931); [4] summary statistics from Davivongs (1963); [5] data from Macho (1991, pers. comm.); [6] summary data from Rubin et al. (1992); [7] data from Kiyono & Hirai (1928); [8] summary statistics from Bada & Endo (1982); [9] data from Parsons (1914); [10] summary data from Corrain & Capitanio (1968, 1976) and Corrain (1986); [11] summary statistics from Schreiner (1935); [12] summary statistics from Nwoha (1991); [13] data from Bridges (pers. comm.); [14] summary statistics from Singh et al. (1986); [15] data from Murrill (1968); [16] summary statistics from Yamaguchi (1993); [17] data from Tardieu (pers. comm.); [18] data from Hirai & Tabata (1928); [19] summary statistics from Yoshioka et al. (1987); [20] summary statistics from Weidenreich (1941); [21] summary statistics from Twiesselmann (1961); [22] data from Hoagland (pers. comm.); see Hoaglund & Weng (1980).

these cases of minimal weight-bearing, the femoral neck remains in a coxa valga position. Surgical correction of the condition with consequent normal weight-bearing produces 'a gradual decreasing of the (neck-shaft) angle of the femur' over a period of a maximum of 2 years (Serafimov, 1974).

In addition, Houston & Zaleski (1967) demonstrated that, in immature individuals, the degree of decrease in femoral neck-shaft angle during development is correlated with the level of normal physical activity. The higher the activity level, the greater the decrease in neck-shaft angle from the neonatal value as the individual matures. From an adaptive perspective, the more varus orientation of the femoral neck, or the decrease in its neck-shaft angle, acts to reduce the moment at the hip joint, tending to sublux the femoral head (Radin & Paul, 1974) and thereby produces a more stable joint; this is especially relevant during the first decade of life, when the acetabulum is largely cartilaginous. These considerations thus indicate that the femoral neck-shaft angle is heavily influenced by load levels in the hip region during development.

At the same time, several studies (e.g. Charpy, 1885; Humphry, 1889; Laplaza et al. 1993, Trinkaus, 1993; Yamaguchi, 1993) have shown that the neck-shaft angle is very stable from midadolescence through most of adulthood. Some decrease has been observed in cases of hip arthrosis (Moore et al. 1994), but the extent of possible correlation with a third factor (e.g., obesity) remains unclear.

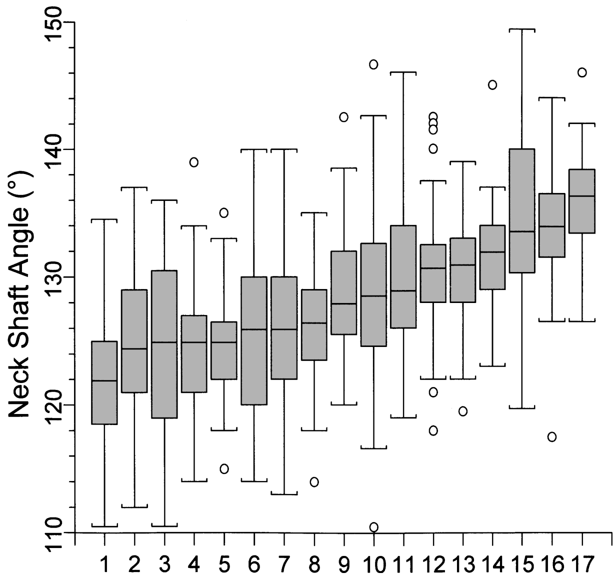

Fig. 1. Box plot distributions for femoral neck-shaft angle for the 17 samples for which individual data are available, arranged in ascending order of median values. Each box plot provides the median, the interquartile range (IQR–box), whiskers to the furthest point within 1.5 times the IQR from the limits of the IQR, plus any outliers. The samples are: 1, South Africans; 2, Rio Grande Amerindians; 3, Early modern humans; 4, Japanese Jomon; 5, Neolithic Japanese; 6, Mesolithic; 7, Medieval British; 8, Pecos Amerindians; 9, Medieval Serbians; 10, Modern French; 11, Albuquerque Euroamericans; 12, Modern Japanese; 13, Woodland Amerindians; 14, Mississippian Amerindians; 15, Northeast US Euroamericans; 16, Easter Islanders; and 17, Modern Chinese.

General patterning

Femoral neck-shaft angles show considerable variation both within and between human populations. Mean values range from 122°–136°, and normal individuals are found from around 110° to almost 150° (Table 1; Fig. 1). Given the high degree of variation within populations, it is not surprising that there is considerable overlap between the ranges of variation. As a result, the mean of the sample with the highest mean is 3 standard deviations above the mean of the sample with the lowest angles. At the same time, the central portions of the sample distributions remain relatively modest, since the interquartile ranges extend from 4.5° to 11.5° and all except the 2 geographically heterogeneous early samples (the prehistoric Paleolithic and Mesolithic ones) have interquartile ranges $< 10°$.

Sexual variation

Given differences in levels of postcranial robusticity (Trinkaus, 1980) and relative biacetabular breadth (Tague, 1989) between males and females within populations, it would not be surprising to find consistent patterns of sexual dimorphism in femoral neck-shaft angles. When the distributions of the angles are compared between the sexes within samples, however, the patterning does not support a conclusion of consistent sexual dimorphism (Table 2). The female mean angle is higher in 58.8% of the 17 samples providing separate male and female data, suggesting lower activity levels relative to males. However, in only 6 of the samples does the difference reach

Table 2. *Sexual differences in femoral neck-shaft angles* (*in degrees*)*

	Males (deg)	Females (deg)	*P*	Male minus female (deg)
Foragers				
Khoisan (South Africa)	121.4 ± 4.5 (28)	125.8 ± 5.0 (19)	0.004	−4.4
Eurasian Paleolithic early modern humans	123.2 ± 7.0 (13)	125.3 ± 8.6 (11)	0.522	−2.1
East Asians—Yoshiko Jomon (Japan)	125.5 ± 4.2 (60)	123.5 ± 4.7 (57)	0.017	2.0
Australians	127.8 ± 4.3 (150)	127.3 ± 5.0 (110)	0.389	0.5
Agriculturalists				
Africans (South Africa)	121.1 ± 4.2 (201)	122.9 ± 4.8 (160)	< 0.001	−1.8
Amerindians—Rio Grande Pueblo (USA)	123.2 ± 6.1 (40)	126.3 ± 4.5 (40)	0.010	−3.1
East Asia—Tsukumo Neolithic (Japan)	125.1 ± 4.1 (21)	124.2 ± 3.7 (25)	0.458	0.9
Europeans—Rothwell Medieval (Britain)	126.6 ± 5.6 (78)	125.9 ± 4.4 (56)	0.462	0.7
Sub-Saharan Africans—Zulus (South Africa)	125.8 ± 6.4 (25)	127.6 ± 6.2 (25)	0.329	−1.8
Africans (Nigeria)	131.3 ± 5.8 (138)	128.6 ± 7.8 (118)	0.002	2.7
Amerindians—Illinois Woodland (USA)	130.4 ± 3.1 (83)	131.2 ± 3.9 (69)	0.163	−0.8
South Asians (India)	132.8 ± 4.0 (101)	126.3 ± 3.2 (50)	< 0.001	6.5
Amerindians—Illinois Mississippian (USA)	131.1 ± 3.7 (24)	132.4 ± 3.6 (24)	0.311	−1.3
Urban				
Europeans—Paris (France)	129.1 ± 7.4 (37)	129.2 ± 6.7 (36)	0.968	−0.1
Euroamericans—Albuquerque (USA)	128.9 ± 5.4 (38)	130.5 ± 5.7 (17)	0.344	−1.6
East Asians—Kinai (Japan)	130.9 ± 4.5 (30)	130.0 ± 5.6 (20)	0.537	0.9
Euroamericans (Canada)	129.0 ± 7.3 (16)	133.0 ± 6.6 (16)	0.118	−4.0

* *P* values are from paired *t* tests, except for the Nigerian and Indian samples for which means are compared.

Table 3. *Right-left asymmetry in femoral neck-shaft angles (in degrees)**

	Right (deg)	Left (deg)	*P*	Right minus left (deg)	N
Foragers					
East Asians—Yoshiko Jomon (Japan)	122.5±4.8	125.6±4.5	< 0.001	−3.1	72
Agriculturalists					
Africans (South Africa)	122.6±4.9	121.2±4.9	< 0.001	1.4	361
East Asians—Tsukumo Neolithic (Japan)	125.1±4.1	125.2±4.3	0.876	−0.1	39
South Asians (India)	131.0±3.6	131.3±3.9	0.488	−0.3	151
Africans (Nigeria)	130.4±6.8	129.7±6.6	0.242	0.7	256
Amerindians—Illinois Woodland (USA)	132.2±4.6	132.1±4.6	0.874	0.1	26
Urban					
Euroamericans—San Francisco (USA)	134.9±6.2	133.7±7.0	0.243	1.2	36
East Asians—Kinai (Japan)	130.2±4.9	131.3±4.9	0.008	−1.1	48
East Asians—Hong Kong (China)	136.9±5.4	137.1±4.7	0.796	−0.2	44

* *P* values are from paired t tests, except for the Nigerian and Indian samples for which means are compared.

significance at the $P < 0.05$ level, and in only 5 samples does the mean difference exceed the approximately 1°–2° of reasonably expected intraobserver error. Consequently, any sexual differences are small and inconsistent.

Asymmetry

Asymmetry in the human lower limb is frequently assumed to be low and random with respect to side, although some authors (e.g. Ruff & Jones, 1981; Macho, 1991; Nwoha, 1991; Trinkaus et al 1994; but see Webber & Garnett, 1976) have noted variably greater degrees of left leg robusticity in individual samples. If greater left leg robusticity is the dominant pattern, this should be reflected in lower neck-shaft angles on the left side.

Unfortunately, the assumption of low and/or random asymmetry has led to most researchers to measure only one side. Nonetheless, data exist to evaluate asymmetry for 9 samples (Table 3), including raw measurements for 7 samples and summary statistics for right and left femora of the same individuals for the other 2 samples. We have consequently graphically plotted individual right minus left differences in angles for the first 7 samples (Fig. 2) and computed probability values for matched pairs of femora for those samples (Table 3). *P* values are also provided for the right-left means for the other 2 samples. The resultant plot (Fig. 2) shows considerable ranges of asymmetry in most samples. However, all but 1 of the medians cluster around 0°. Similarly, the differences between the means (Table 3) are, except for 1 case (Japanese Jomon), less than 2° and 5 of them are essentially zero. In 2 of the cases with a significant difference (South Africans and modern Japanese),

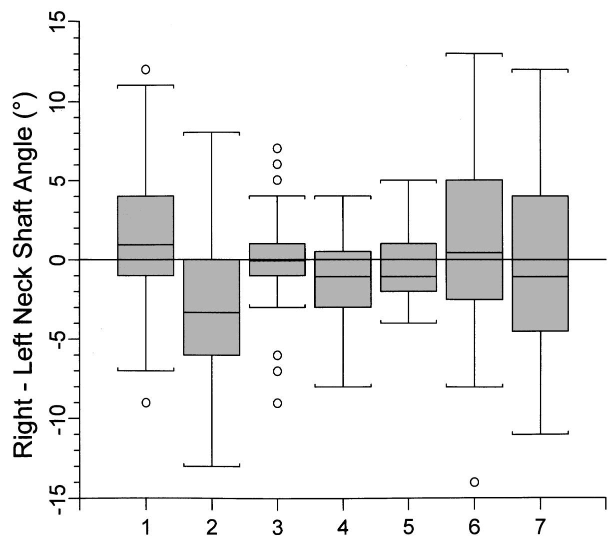

Fig. 2. Box plot distributions of right minus left neck-shaft angles, indicating level and direction of asymmetry. The samples are: 1, South Africans; 2, Japanese Jomon; 3, Neolithic Japanese; 4, Modern Japanese; 5, Woodland Amerindians; 6, Northeast US Euroamericans; and 7, Modern Chinese.

the mean difference is very small, and they contrast as to which side has the higher angle. In the 1 case of marked symmetry, it is the left side which has the higher neck-shaft angle.

These data therefore indicate that considerable individual asymmetry ⩾ 5° is not unusual. However, there is little within sample patterning as to which side has the higher angle.

Interpopulational patterning

Despite the crudeness of using general subsistence level as an indicator of locomotor mobility and activity level, especially for the developmental periods

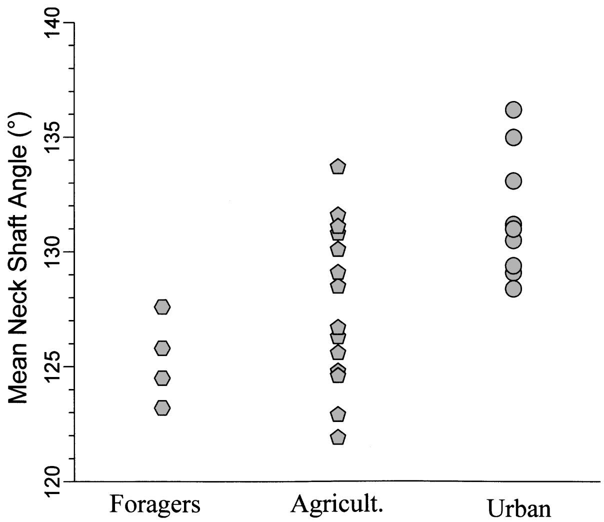

Fig. 3. Distributions of the mean neck-shaft angles for economic categories of prehistoric and modern samples.

during which most of the decrease in neck-shaft angle takes place, there is a consistent pattern of increasing mean angles with an increasingly sedentary existence and with mechanisation (Table 1; Fig. 3). On average, the nonmechanised hunting and gathering peoples have the lowest angles, and the urban samples have the highest ones, with the agricultural groups being more variable and overlapping the 2 extreme groups. A Kruskal–Wallis test across the means of the 30 samples gives $P = 0.003$, with pairwise Wilcoxon rank-sum test P values of 0.099 for the forager-agricultural comparison, 0.003 for the forager-urban one, and 0.011 for the agricultural-urban one. Therefore, despite between sample variation within each category, there is a robust pattern of increasing neck-shaft angles with decreasing mobility and increasing mechanisation.

These data also make it apparent that the relatively high angles commonly encountered in modern industrial societies cluster at the high end of normal recent human ranges of variation. Lower values, even below 120°, are by no means unusual in medically normal individuals in nonindustrial societies.

In addition, given the possibility that ecogeographic patterning in body form (Ruff, 1994; Holliday, 1995), as well as undefined 'racial' variation, might influence neck-shaft angles, the samples were divided geographically and ranked according to latitude. The comparison of Sub-Saharan African, European/Mediterranean, east Asian, and Native American groups (the Australian and Polynesian samples are not included) using a Kruskal–Wallis test across their means produced a nonsignificant $P = 0.505$. Moreover, a Spearman's rank-order correlation analysis between mean neck-shaft angle and latitude yielded an essentially random $\rho = 0.014$. Consequently, geography, climate and 'race' appear to have little effect on patterning in femoral neck-shaft angles.

Summary

A survey of femoral neck-shaft angles across a representative sample of recent and modern human population documents the high degree of normal variability encountered in this orthopaedically relevant region. Even though individual bilateral asymmetry exists in these angles and some samples exhibit sexual dimorphism, there are no consistent patterns in either respect, nor is there any geographic patterning to femoral neck-shaft angles. However, there is a strong correlation between economic level and average neck-shaft angles, reflecting the effects of differential activity levels during ontogeny on the degree of decrease in the angle.

ACKNOWLEDGEMENTS

P. S. Bridges, J. A. Heller, F. T. Hoaglund, G. A. Macho, and C. Tardieu kindly provided original data for several recent human samples, and K. Aoki provided copies of the publications of modern and Neolithic Japanese skeletal remains. To all of them we are grateful.

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